Research Statement

Paul Varkey

December 9, 2010

My dissertation is titled \textit{Bounded Rational Automated Bilateral Negotiation} and generally deals with computational and epistemological issues that arise under strategic multiagent interactions under uncertainty, in particular in the problem of automated bilateral bargaining ([Kra95, FSJ98, PSJ98, FKSBY02, FWJ01, JFL+01, Kra01, LS01, LS02, FWJ05]). Broadly speaking, my work is motivated by the interactive epistemological approach to both game theory ([Har68], [MZ85], [AD93], [Aum99a], [Aum99b], [BB99] and [Zam08]) and decision theory ([GD05] and [DG05]). I am interested in developing \textit{computationally tractable} and \textit{boundedly rational} ([ZR95, Rub98]) algorithms for autonomous agents that have to make decisions and plan while interacting sequentially in uncertain environments possibly containing other agents with possibly conflicting interests and goals. In particular, I have situated all my efforts pertaining to this research problem in developing models and algorithms for one concrete object of study – \textit{Bilateral Bargaining under Uncertainty}.

**Thesis Research Summary**

In my research, I address the problem of ‘Bilateral Bargaining under Uncertainty’ – an important and well-studied example of multiagent optimal sequential planning. Operating within a purely subjective optimality paradigm, I provide novel insights into \textit{achieving autonomous bounded rationality in sequential multiagent environments under uncertainty} by obtaining two important results: (a) in applying a strictly Bayesian finite interactive epistemological decision-theoretic (FIE-DT) model (namely, the Finitely Nested I-POMDP) to the problem, a subtle complexity-theoretic understanding of the optimal dynamic program led to a natural realization of bounded rationality as a tradeoff between solution quality (optimality) and speed (efficiency), and (b) in a FIE-DT model that is prior-free (non-Bayesian) at higher levels, I uncover the essence of the connection between an agent’s epistemology and its optimal behavior – a regular relationship between its beliefs and optimal actions under a suitable ordering of the beliefs – which I exploit to realize approximate higher-order reasoning through an offline-online boundedly rational algorithm.

The I-POMDP ([GD05, DG05]) extends the POMDP ([Lov91, Mon82, KLC98]) and is the first formalization of a completely subjective and strategic approach to realizing Bayesian decision-theoretic autonomous rationality in a multiagent environment – here an agent is utility-theoretic and hence, Bayes-rational and is equipped with beliefs about the physical world and other agents. Therefore, an agent’s beliefs may also be about another agent’s beliefs, which, in turn may be about other agents’ beliefs – this recursive nesting may be arbitrarily deep, i.e. infinite. The Finitely Nested I-POMDP is a computable version of this model maintains only finite levels of the infinite belief heirarchy. This elegance of this model inspired my own construction of FIE-DT bargaining agents. I notice that the optimal dynamic program is exponential in the dimension of the discretized action space (the true action space is continuous). Therefore, I realize bounded rationality in this approach through an anytime algorithm that obtains “poor” results quickly by beginning with a coarse discretization resolution and then refining and repeating until interrupted. Along the way, I also demonstrate the practical usefulness of memoization for this problem. In addition, I show how one may avoid “0”-probability events by maintaining ensemble models in the prior support (this is crucial for the success of any Bayesian decision-making framework – sequential or otherwise). These results are forthcoming in [VG11a]. Some of the results from this work were also presented at the Dynamic Epistemic Logic track at NASSLLI’10 ([Var10b]).

The I-POMDP model as currently defined requires the finiteness of the space of observations/actions. Generalization to infinite spaces is at least non-trivial, if at all possible. Furthermore, I study the bargaining
problem under the natural assumptions of deterministic transitions and perfect observations. Uncertainty enters only through the (interactive) epistemic component – an agent is unsure of what other agents believe. Under such settings, particle filtering approaches fail spectacularly. Therefore, in the absence of a general method of Bayesian higher-order belief update in deterministic and perfectly monitorable multiagent environments with infinite observation/action spaces, I propose a prior-free (i.e. Bayesian) method of approximate higher-order reasoning. I first make the following observation: a lexicographic moment-based ordering on the space of lower-order beliefs induces a natural order on the argmax space of corresponding optimal actions. This enables the following natural offline-online bounded rational algorithm: (a) generate samples of lower-order beliefs that are well-dispersed according to the ordering (b) solve them offline (c) during online interaction, use the actual offer to locate the closest pre-solved belief (and, optionally, depending on available time, (c.1) refine search further in the vicinity of this belief under the same ordering) and (d) best-respond to the prescription of the solved belief. The number of samples solved (step (a)) may be increased and the refined search conducted in the vicinity (step (c.1)) may be increased depending on the availability of offline and online time, respectively. These results are forthcoming in [VG11b]. Some of the preliminary results from this work were first reported in [VG10].

Earlier work: (a) Behavioral and (b) Game-Theoretic

The above important results were obtained from my most recent work and form the core of my thesis. However, my earliest studies on the bargaining problem involved the construction of a behavioral bargaining agent, in which offers are made and anticipated using the following simple principle: large deceptions are rarely made and are less likely compared to small deceptions. The corresponding offer strategies and likelihoods are realized as exponential distributions, epistemic deliberations are Bayesian (realized using particle filters) and the agents are Bayes-rational. The results obtained roughly resemble human bargaining behavior, as expected.

Following this, I surveyed the vast game-theoretic literature on sequential rationality ([FL81a, FL82, FL81b, KW82, FT91]) and bargaining under incomplete information ([Rub82, Rub85], [ST83], [Cra84], [FT83], [GP86], [Per86] and [Cho90]). The variety of results, although interesting, regarded only situations where an agent’s first-order beliefs are assumed common knowledge. I relaxed this assumption to slightly more generalized epistemic settings: where the common knowledge assumption was made only at the second-order or third-order level. I derived Perfect Bayesian Equilibria (PBE) for these settings and obtained sensitivity results. The empirical evidence points to the diminishing influence of higher orders of beliefs (relative to lower orders) on the PBE solution (a recent result in the theory may indicate this phenomenon). This results was recently reported in [Var10a]. This aspect of my work is only intrinsically interesting, mainly because the game-theoretic equilibrium solution concept is incomplete and non-specific ([KL82] and [Bin90]) and sometimes epistemologically untenable ([AB95]) and is therefore not operationalizable as a control paradigm for an AI ([SPG03]). This also accounts for my philosophical transition to a purely decision-theoretic (subjective expected utility maximization) approach towards optimal sequential planning problems where, instead of searching for equilibria, the agents maintain beliefs about the opponents type and then choose actions that maximizes its expected utility in the resulting interaction.

References


